International Journal of Energy and Power
IJEP Volume 1, Issue 1, August 2012 PP. 26-30
ISSN(online)
ISSN(print)
www.ij-ep.org

Capacitor Placement Optimization in Transmission System Using Hybrid PSO and HBMO Algorithms

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Abstract: This paper presents particle swarm optimization (PSO) and honey bee mating optimization (HBMO) algorithms for capacitor placement in the power transmission system so that determines the optimal locations and number of capacitors with an objective of voltage profile improvement and power loss reduction. The solution methodology has two parts: part one determines the number and size of capacitors and in part two a new hybrid PSO and HBMO algorithms is used to estimate the optimal bus of capacitors at the optimal sizes and numbers at part one. The main advantage of the proposed method is faster run speed than other methods. The proposed method is applied to 14-bus IEEE transmission system. The results obtained by the proposed method are compared with PSO method. The proposed method has outperformed the other methods in terms of the quality of solution (Convergence speed and size of the objective function).

Keywords: Transmission System; Particle Swarm Optimization (PSO); Honey Bee Mating Optimization (HBMO); Voltage Profile; Loss Reduction.

1. INTRODUCTION

In an electrical energy system, we often calculate parameters such as voltage of buses, power generation, and power system losses. Network of 14 bus IEEE system is an example system for transmission network and newton raphson method is used for load flow in this system. Various methods have been presented for capacitor placement optimization in recent years. The optimal size and location of suitable capacitor is presented in [1]. A distribution system expansion planning strategy encompassing renewable DG systems with schedulable and intermittent power generation patterns is presented in [2] that a solution algorithm integrating TRIBE PSO and ordinal optimization (OO) is developed to obtain optimal and near-optimal solutions for system planners. In [3] a distributed micro-grid planning model has been presented to optimize the locating and the unit capacities within DG micro-grid, in which wind power and photovoltaic power are taken into consideration simultaneously with both Elitism Genetic Algorithm (EGA) and PSO.

A multi-objective index-based approach for optimally determining the size and location of multi-distributed generation (multi-DG) units in distribution systems with different load models based on PSO is introduced in [4,5] and a combined genetic algorithm (GA)/(PSO) is presented in [6] for optimal location and sizing of DG on distribution systems. A population-based heuristic approach for optimal location and capacity of DGs in distribution networks, with the objectives of minimization of fuel cost, power loss reduction, and voltage profile improvement is proposed in [7] that the approach employs an improved group search optimizer (iGSO) by incorporating PSO into group search optimizer (GSO) for optimal setting of DGs. A new hybrid method which employs discrete PSO and optimal power flow is introduced in [8] which could apply to connect distributed generation systems in a distribution network choosing among a large number of potential combinations.

Therefore in this paper we consider the improvement in voltage profile and reduction system losses, as the problem of mathematical modeling and algorithm is solved using a hybrid PSO&HBMO. The organization of this paper is as follows: The problem formulation is presented in Section 2. The PSO algorithm is in Section 3. The HBMO algorithm is represented in Section 4. Simulation results on 14 bus IEEE system are given in Section 5.

2. PROBLEM FORMULATION

The objective of capacitor placement in the transmission system is to minimize the losses and improve voltage profile. For simplicity, the operation and calculation of the capacitor placed in the transmission system assume that three-phase system is considered as balanced and loads are assumed as time invariant. Mathematically, the objective function of the problem is minimizing the loss and voltage deviation. This function is:

$$F = W_1 \times P_{loss} + W_2 \times \sum_{i=1}^{14} (1 - v_i)^2 \quad (1)$$

Where w_1 and w_2 are the objective function coefficients. P_{loss} and v_i are the total loss in transmission system and the voltage magnitude of bus i. The voltage magnitude at each bus must be maintained within its limits and is expressed as:

$$v_{\min} < |v_i| < v_{\max} \tag{2}$$

Where $|v_i|$ is the voltage magnitude of bus i, $v_{\min}$ and $v_{\max}$ are bus minimum and maximum voltage limits, respectively. The power flow is computed by following equation:

$$p_i = |v_i| \sum_{j=1}^{n} |y_{ij}| |v_j| \cos(\delta_i - \delta_j - \phi_{ij}) \tag{3}$$

$$Q_i = |v_i| \sum_{j=1}^{n} |y_{ij}| |v_j| \sin(\delta_i - \delta_j - \phi_{ij}) \tag{4}$$

Where P_i and Q_i are the real and reactive power flowing out of bus i. $|y_{ij}|$ and ϕ_{ij} are the Size and angle of impedance. δ_i And δ_j are the angle of voltage at bus i and j.

$$I_{ij} = \frac{v_i - v_j}{z_k} - \frac{1}{2} y_k v_i \tag{5}$$

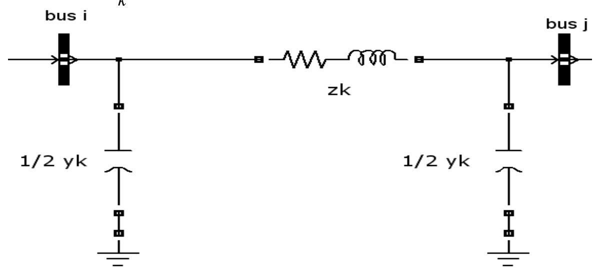

Figure1: Π model of transmission line between buses

Where z_k and y_k are the admittance and impedance line k. I_{ij} are the current from bus i to bus j.

$$S_{ij} = v_i I_{ij}^*,\ S_{ji} = v_j I_{ji}^*,\ S_{lossk} = S_{ij} - S_{ji},\ P_{lossk} = real(S_{lossk})$$

$$P_{lossk} = \sum_{k=1}^{n} P_{lossk} \tag{6}$$

3. PSO ALGORITHM

PSO is a population-based, stochastic optimization algorithm based on the idea of a swarm moving over a given landscape. The algorithm adaptively updates the velocities and members positions of the swarm by learning from the good experiences [9, 10]. In PSO, the velocity v_i^d and position x_i^d of the *d*th dimension of the *i*th particle are updated as follows:

$$v_i^d = w \cdot v_i^d + c_1 \cdot r_1 \cdot (pbest_i^d - x_i^d) + c_2 \cdot r_2 \cdot (gbest^d - x_i^d) \tag{7}$$

$$x_i^d = x_i^d + v_i^d \tag{8}$$

Where

x_i :the position of the ith particle

v_i : the velocity of particle *i*

$pbest_i$:the best location in the search space ever visited by particle *i*

gbest :the best location discovered so far

w: the inertia weight that controls the impact of previous velocity of particle on its current one

r_1, r_2: independently uniformly distributed random variables with range (0, 1)

c_1,c_2 : positive constants(acceleration) coefficients which control the maximum step size

In PSO, equation (7) is used to calculate the new velocity according to its previous velocity and to the distance of its current position from both its own best historical position and the best position of the entire population or its neighbourhoods [11, 12]. Generally, the value of each component in *v* can be clamped to the range [$-v_{max}$, v_{max}] to control excessive roaming of particles outside the search space. Then the particle flies toward a new position according equation (8). This process is repeated until a user-defined stopping criterion is reached. A linearly decreasing inertia weight from maximum value w_{max} to minimum value w_{min} is used to update the inertia weight:

$$w^k = w_{\max} - \frac{w_{\max} - w_{\min}}{k_{\max}} \cdot k \tag{9}$$

K_{max} is maximum iteration number [13, 14].

4. HBMO ALGORITHM

The honey bee is a social insect that can only survive as a member of a community, or colony. The colony inhabits an enclosed cavity. The honey bee community structurally consists of three different forms: the queen (reproductive female), the drone (male), and the worker (non reproductive female). These castes are associated with different functions in the colony; each caste possesses its own special instincts geared to the needs of the colony. The behaviour of honey-bees shows many features like cooperation and communication, so honey-bees have aroused great interests in modeling intelligent behaviour these years. Marriage in honey-bees optimization (MBO) is a kind of swarm-intelligence method. Such swarm intelligence has some successful applications. Ant colony is an example and the search algorithm is inspired by its behaviour. Mating behaviour of honey-bees is also considered as a typical swarm-based optimization approach. The behaviour of honey-bees is related to the product of their genetic potentiality, ecological and physiological environments, the social conditions of the colony, and various prior and ongoing interactions among these three [15, 16]. The HBMO algorithm combines number of different procedures. A drone mates with a queen probabilistically using an annealing function as follows [15, 17]:

$$prob(Q, D) = e^{\frac{-\Delta(f)}{s(t)}} \tag{10}$$

where Prob(D) is the probability of adding the sperm of drone D to the spermatheca of the queen, Δ is the absolute difference between the fitness of D and the fitness of the queen and S(t) is the speed of the queen at time t. The probability of mating is high when the queen is with the high speed level, or when the fitness of the drone is as good as the

queen's. After each transition in space, the queen's speed decreases according to the following equations:

$$s(t+1) = \alpha \cdot s(t) \quad 0<\alpha<1 \tag{11}$$

Where ∝ is the amount of speed and energy reduction after each transition and each step. Initially, the speed of the queen is generated at random. A number of mating flights are realized. At the start of a mating flight drones are generated randomly and the queen selects a drone using the probabilistic rule in Eq. (10). If the mating is successful (i.e. the drone passes the probabilistic decision rule), the drone's sperm is stored in the queen's spermatheca. By using the crossover of the drone's and the queen's genotypes, a new brood (trial solution) is generated, which can be improved later by employing workers to conduct local search. One of the major differences of the HBMO algorithm from the classic evolutionary algorithms is that since the queen stores a number of different drone's sperm in her spermatheca, she can use parts of the genotype of different drones to create a new solution which gives the possibility to have fittest broods more. In real life, the role of the workers is restricted to brood care and for this reason the workers are not separate members of the population and they are used as local search procedures in order to improve the broods produced by the mating flight of the queen. Each of the workers has different capabilities and the choice of two different workers may produce different solutions. This is realized with the use of a number of single local search heuristics $N_{worker1}$ and combinations of them $N_{worker2}$. Thus, the sum of these two numbers $N_{worker}= N_{worker1} + N_{worker2}$ gives the number of workers. Each of the broods is randomly chosen to be feed by worker, which is also randomly selected. If the new brood is better than the current queen, it takes the place of the queen. If the brood fails to replace the queen, then in the next mating flight of the queen this brood will be one of the drones. Honey Bee Mating Optimization (HBMO) algorithm can be described briefly in 5 steps as below [18]:

Step 1: This algorithm starts with flying in which the queen (the best answer) randomly selects its male pairs to consequently reproduce new bees.

Step 2: the new born bees (possible answers) will be reproduced by displacing in queen and male genes.

$$child = parent1 + \beta \cdot (parent2 - parent1)$$

$$0\leq\beta\leq1 \tag{12}$$

Step 3: worker bees (research functions) are used to do the position seeking (breeding and improving new bee's generation).

$$Brood_i^k = Brood_i^k \mp (\delta+\varepsilon) \cdot Brood_i^k \tag{13}$$

$$0<\varepsilon<1;\ 0\leq\delta\leq1$$

Step 4: Fitting functions of the workers will be sorted based on the amount of bees' generation improvement.

Step 5: the best new born bee in this process can be nominated to take queen position and do the next flying process.

In this article a new optimization method is presented based on the mixture of PSO and HBMO methods. Players and motion speed is calculated through PSO relations in this method and choosing or suitability is obtained from HBMO method. Suitability analysis is performed using prob. function in HBMO method. In (10) S(t) is equal to particle speed in PSO method and Δ(f) is showing difference from general optimized amount which can be calculated as below:

$$\Delta(f) = gbest(it,:) - particleposition(i) \tag{14}$$

where gbest(it,:) is the best amount in all conditions and particle position (i) is the present position of the particle.

5. SIMULATION RESULTS ON 14-BUS IEEE SYSTEM

The proposed method has been programmed using MATLAB software. The effectivenss of the proposed method is simulatated by capacitor placement test on 14-bus IEEE system for losses reduction and voltage profile improvement.

In this paper, IEEE 14-bus system is chosen for the case study. The original system consists of two generators, three synchronous compensators, 11 loads, three transformer, 14 buses and 15 lines. The system is shown in figure 2. Voltage profile is shown in figure 3.

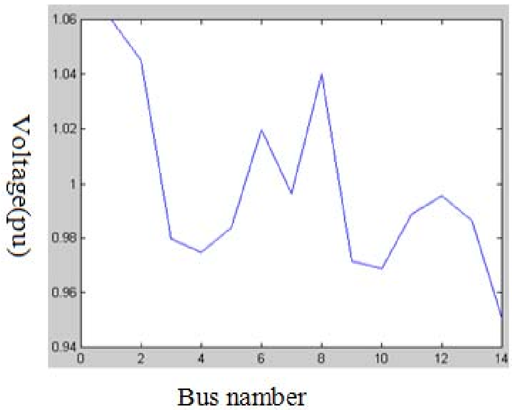

Figure2: IEEE 14-bus system

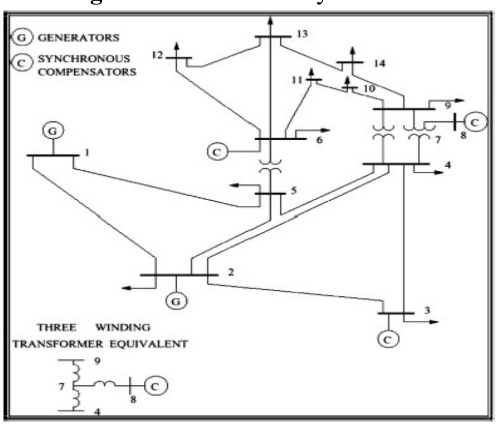

Figure3: Voltage profile in 14-bus system

First is shown the objective function value and the second is given the convergence speed of the proposed method. For this

purpose, table 1 and figure 4 show capacitor numbers and objective function values.

Table1: objective function value for two optimization method

Capacitor	PSO	PSO&HBMO
One	9.3326	9.3326
Two	9.2995	9.2995
Three	9.2932	9.2932
Four	9.3039	9.3044
Five	9.3146	9.3278

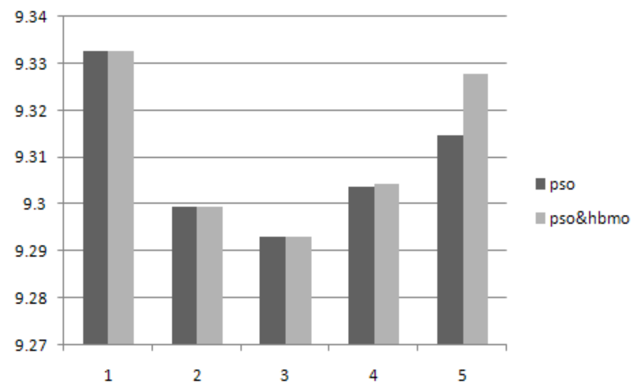

Figure4: Objective function values diagram

Table 2 shows the iteration number of PSO and PSO & HBMO methods. It is observed that from table 2 PSO & HBMO method is faster than the PSO method.

Table2: The iteration number of PSO and PSO & HBMO methods

Capacitor	PSO	PSO&HBMO
One	2	1
Two	3	2
Three	11	7
Four	14	8
Five	20	9

6. CONCLUSIONS

In this paper, a hybrid PSO&HBMO algorithm proposed for optimal capacitor placement in transmission system. This method efficiently minimize the total power loss, variance of voltage,amount of objective function and improve the voltage profile satisfying transmission line limits and constraints. It can be concluded that if the convergence speed to be important the PSO&HBMO algorithm can be used otherwise if the value of the objective function to be important the PSO method is selected.

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